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DEFECTS AND MATERIALS CHARACTERIZATION BY ANALYSIS
OF ULTRASONIC SIGNALS.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Recent techniques in defects and materials characterization are reviewed and some of them selected to be implemented at INTA's Ultrasonic Lab. Previous work includes design and manufacture of several items (ultrasonic test bed, facsimile recorder)as well as familiarization with instrumentation. Main effort in this first year has been devoted to prepare software and to test it via elementary experiments on materials characterization. ↵

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## PREFACE

The present work has been performed at the Ultrasonics
Laboratory of the Department of Structures and Structu-
ral Materials of INTA as a first part of a two year pro-
gram.

The first period is mainly devoted to setting up the ins-
trumentation, technique and software to be used in the
second year. It also includes the necessary period for
all the research personnel involved to become familiar
with new techniques and instrumentation.

This work has been funded in part by European Office of
Aerospace Research and Development under grant number
EOARD-82-0316.

The author wishes to acknowledge the effort of J. Miguel
Alvarez in preparing the software as well as that of E.
Gallego del Pozo in designing and making auxiliary equip-
ment.

1 - <u>General</u>

The work reported here was programmed as a part of a
wider research project of the Ultrasonic Laboratory of
the Structures and Structural Materials Department  of
the INTA.  An ultrasonic spectroscopy research program
was formerly developed under the sponsorship of Spanish
Government.  Analog techniques used in this project
soon proved to be unsuitable to perform adequate reflec-
tor characterization and, therefore, it was decided to
implement the necessary instrumentation to digitize and
computer process the signal.

In November 1981 a proposal was submitted to ECARD inclu-
ding several goals to be specified later.  The proposal
was approved and EOARD gave some useful recommendations
for the best development of the work and in order to co-
ordinate with other works already in progress in other
Laboratories in the United States.  With this aim,  a
trip was programmed to attend the Annual DARPA/AFML
Review of Progress in Quantitative Nondestructive Eva-
luation to be held in La Jolla, California, and to visit
Ames Laboratory of Iowa State University and Rockwell
International Science Center (Thousand Oaks, California).
A visit to NASA Lewis Research Center (Columbus, Ohio)
was also suggested but, because of unknown reasons, it
was not possible to arrange this visit.  In any case,
the information obtained during this trip, which took
place in August 1982, as well as those from several
"Proceedings of the DARPA/AFML Review of Progress in
Quantitative NDE" supplied by London Office of the EOARD
have been of major help in defining the objectives and
selection test techniques.

One of the aims more clearly defined was the defect cha-
racterization subject that absorbs the largest portion
of the scientific work carried out under DARPA/AFML

sponsorship since 1973. Ultrasonic test quantification, in particular, is one of the main objectives of this project which tends to reduce the numerous sources of uncertainity found in conventional tests.

Therefore, it was decided to dedicate a part of the work to defect characterization and, after consulting availa-ble bibliography, two different techniques seemed to be the most adequate:

- Comparison of spectral amplitude as a function of the direction of incident beam. It is an empirical method first proposed by E. Domany (1).

- Unidimensional Born inversion. There are many papers available on this technique. We have taken as reference that of R.K. Elsley (2).

On the other hand the development of some technique sui-table for materials characterization to determine elastic mechanical and fracture parameters was considered. The great interest of this objective is generally recognised, due to the high cost of the destructive mechanical tests necessary to make measurements of yield point, ( $\sigma_y$ ) or fracture toughness ($K_{Ic}$, $J_{Ic}$). The Mechanical Test Laboratory of the Department of Structures and Structural Materials of INTA is developing a programme to study the fracture toughness as a function of heat treatment of several national low alloy steels. This gives additional interest to our nondestructive characterization objective and facilities to get suitable samples available.

Materials characterization by ultrasonics is based on the measurements of the acoustic velocity and attenuation as a function of frequency. When results are applied to suitable equations yield point and toughness can be eva-luated. Even considering the limited validity of current

equations, mainly because its empirical character, it seems undoubtfull the usefulness of the works of A. Vary and his group, NASA Lewis Research Center, (Columbus, Ohio) in view of the test systematization and searching a suitable model to explain interaction between elastic waves and inhomogeneities or dislocations present in solids.

Work to be carried out in our Laboratories will be mainly dedicated to check the validity of Vary's empirical equations (3) for materials other than those found in references (maraging steel and titanium alloy).

The definite structure of the works was stablished in the following way:

First year:

- Review of bibliography.
- Familiarization with computer and digital instrumentation.
- Design and fabrication of a precision automatic system for inmersion testing.
- Software for defect characterization.
- Software for materials characterization.
- Preliminary experimental work.
- Design and fabrication of auxiliary equipment.

Second year:

- Setting up the inmersion test system and defect characterization tests.
- Tests for software functionability.
- Complete programme of experimental tests.
- Elaboration of results and conclusions.

It can be said that first year will be devoted to prepare equipment and software and the second year to carry

out the greater part of the experiments.

Because of several administrative difficulties it has
not been possible to complete all the objectives of the
first year.

## 2 - Theoretical bases

### 2.1 - Defect characterization

The technique suggested by E. Domany (1) has a very
simple principle.  It consists in analyzing the frequen-
cy spectrum of two echos coming from different tests
positions.  If the reflector is a sphere it is evident
that the response will be constant as the test angle
varies.  Then, if frequency amplitude from one angle is
represented versus that obtained from the other angle,
a diagonal of the first coordinate quadrant will be ob-
tained unless some uncontrolled influences have gone
into the work.

On the other hand, the curve will become deformed and
apart from the diagonal as the reflector moves away from
the spheric shape.  In this way some information about
reflector shape may be derived.  Results of applying this
technique to two spheroidal reflectors are shown, in fig.
1.



a) spheroid  Semiaxes    b) spheroid  semiaxes   a:0.4mm
     a:0.4mm b:0.2mm                   b:0.1mm
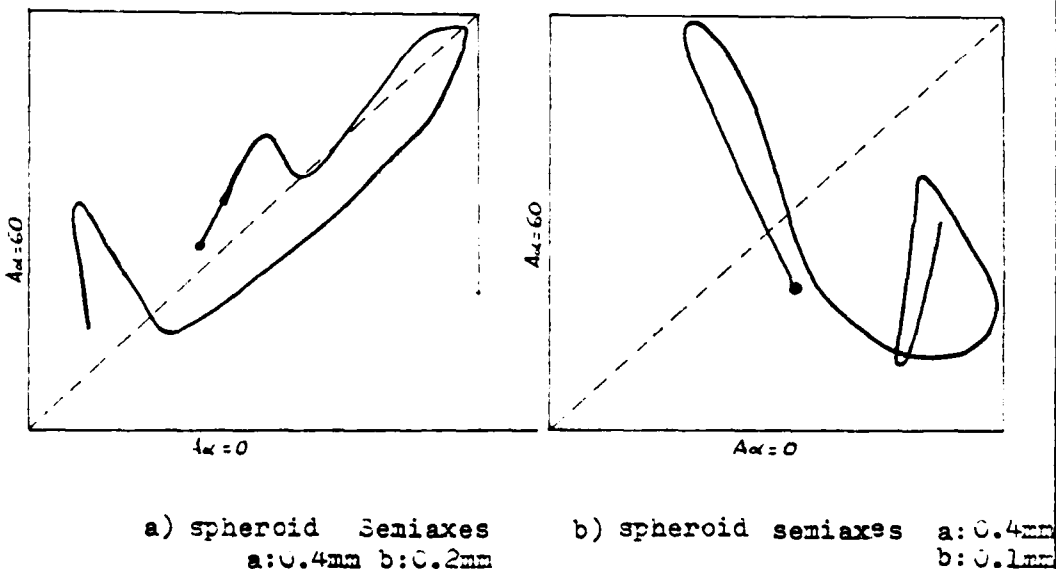
Fig. 1. Spectral amplitude as a function of beam direc-
        tion for two spheroidal reflectors.  Parameter
        is frequency.

Born approximation, in which the inversion algorithm is
based, is a theory useful to explain the weak scatte-
ring that occurs when the difference of the acoustic
impedance between the reflector and the host is low.
It derives a relatively simple mathematical model which
has proved to be useful in order to systematize experi-
mental data. The inversion algorithm coming from this
theory have shown to be adequate even when not strictly
weak scattering occurs. Then, it is not surprising to
find a large number of works related with either the theo-
retical exploration or experimental checking of this new
tool.

In its direct formulation, Born's approximation makes
easier the calculation of $\vec{R}$, which is the signal in the
time domain and that will be received by the transducer
after the interaction of the reflector with an infinitely
short pulse (Dirac's step function). Firstly the res-
pective incident pulse and observation direction must be
defined.

$\vec{R}$ is also known as impulse response and it can be shown
that it is proportional to the second derivative of the
area function $A(s)$ of the reflector's transversal section
projected onto a plane perpendicular to the direction
defined by addition of incidence and observation versors.

The inversion problem may be divided in two parts. The
first one is to determine the characteristic function,
$\gamma(\vec{r})$, of the reflector. That is to say its shape, because
$\gamma(\vec{r})$ is defined as a function that is equal to 1 inside
the reflector and zero outside. The second part of the
problem is to find parameters of the material in particu-
lar $Z$ (acoustic impedance) and $\rho$ (density).

If a sufficient number of data are available for scatte-

ring in several incident directions, $\hat{e}_i$ , the characteristic function is given by the equation:

$$f(\vec{r}) = const. \int d^2 \hat{e}_i \, R \left( t = \frac{2\hat{e}_i \cdot \vec{r}}{v} ; \, \hat{e}_i , -\hat{e}_i \right) \quad (1)$$

where R is the impulse response which is in turn a function of the time. Equation (1) is formulated for back-scattered energy and in consequence the observation direction $\hat{e}_o$ is equal to $-\hat{e}_i$ . If the additional simplification introduced by the spherical symmetry of the reflector is taken into account, equation (1) becomes:

$$f(\vec{r}) = const \frac{1}{2rv} \int_{-2r/v}^{2r/v} R(t; \hat{e}_i, -\hat{e}_i) \quad (2)$$

where $\hat{e}_i$ is arbitrary due to spherical symmetry.

In the frequency domain the characteristic function takes the form:

$$f(\vec{r}) = \frac{1}{2} \int_{-\infty}^{\infty} \frac{1}{v} \, A(\omega) \, d\omega \quad (3)$$

where $A(\omega)$ is the frequency spectrum or, that is the same, the Fourier's transform of the impulse response $R(t)$.

If a single measurement of $R(t)$ is taken, then unidirectional Born inversion can be obtained which gives the reflector radius in the test direction as a distance from its center (time origin) to the plane perpendicular the incident direction and tangent the reflector surface. In order that this technique may produce acceptable results it is necessary that some minimum conditions

be fulfilled because, in certain cases, may become critical:

- Sufficient bandwith of the incident pulse.
- Adequate signal to noise ratio.

Born inversion gives good results in the medium range of frequencies such that:

$$0.5 < kr < 2$$

where $k=2\pi/\lambda$; $\lambda$:wave length; r: reflector radius

If sufficient information is not available in the low frequency range (k.r minimum too high), the estimate value of r is lower than actual value and if high frequency data are missing (kr maximum too low) then r is overestimated. A wide band transducer should have, to be useful for this technique, a range at k of 10:1.

It has been shown in experiments with spheroidal cavities that signal to noise ratio must be kept over 0dB level if estimate radius error is intended to maintain below 20% for a confidence level of 95% (2).

## 2.2 - Materials characterization

Experiments whose theoretical basis is described in (3) and (4) have clearly shown that there are some relationship between acoustic characteristics of a material (acoustic velocity and attenuation) and its fracture toughness. This relation seems to be fairly intuitive because of the dynamic behavior of ultrasonic testing in which the material is forced to transmit elastic stresses through it.

Toughness is measured in classical destructive test by performing a tension (or similar) test in a precracked specimen. However recent studies have shown (5) that the pressure of a sharp crack is not essential in the determination of fracture toughness and is further suggested that the links between the strength properties and the ultrasonic factors are the material microstructural parameters, in particular, these are the size of the second-phase particles and the spacing between them.

It seems to be demonstrated that crack extension proceeds when the length of heavily deformed region surrounding the crack tip is comparable to the length between cracked particles (Fig. 2).

This condition may be expressed by:

$$\delta_c \simeq \ell \tag{4}$$

where $\delta_c$ is the critical crack opening displacement and is related to the other fracture toughness parameters by the following equation:

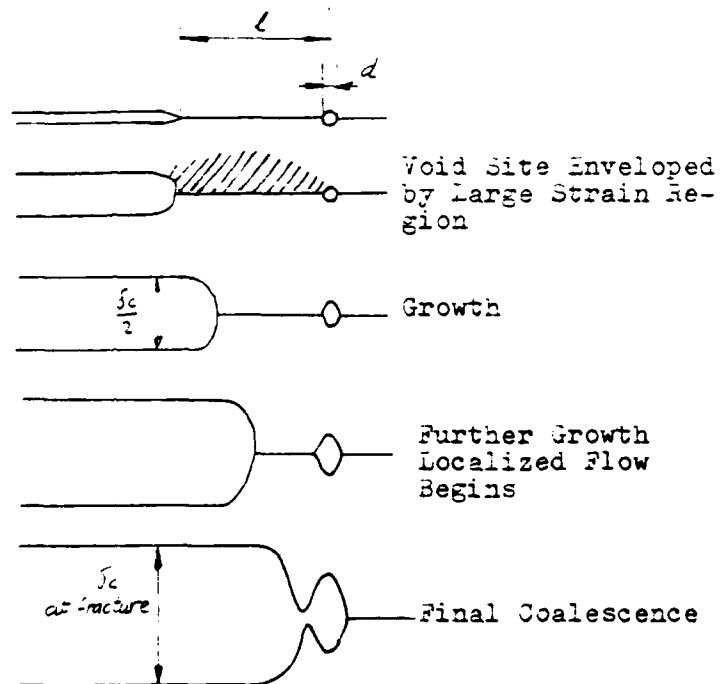$$G_{Ic} = J_{Ic} = \left[ (1 - \nu^2)E \right] K_{Ic}^2 = (1 - \nu^2) \delta_c \tau_y \tag{5}$$

Fig. 2  Growth and coalescence of voids near
crack tip (5).

where $E$, $\nu$ and $\sigma_y$ are Young's modulus, Poisson's ratio and yield stress, respectively.

It is, consequently, easy to show that, at least within the scope of linear elastic fracture mechanics, the following applies:

$$\frac{\sigma_y}{2E} \cdot \left(\frac{K_{sc}}{\sigma_y}\right)^2 \simeq \ell \qquad (6)$$

which establishes a clear relationship between microstructural and fracture parameters.

The purpose of the paper in reference (5) is to attempt to provide a basis for a definite relationship between ultrasonic factors and the fracture toughness reasonably acceptable from the point of view of fracture mechanics.

A quantitie R is defined as:

$$R = \frac{\delta}{\ell + 2\delta} \, \ell n \frac{|\sigma_{zz}^{a}|}{|\sigma_{zz}|} \qquad (7)$$

where $\sigma_{zz}^{a}$ represents the stress intensity field associated with the incident wave and $\sigma_{zz}$ the stress at any point of a medium containing two plate paralels inhomogeneities of thickness $\delta$ and distance $\ell$ between them.

Now, R must be plotted versus $\ell$ with $\delta$ as a parameter and is possible to show that R varies in a noticeably linear way for $\ell$ smaller than 10 $\mu m$ and for a wave number $k\delta = 2\pi$. But, when $k\delta$ differs from $2\pi$, the proporcionality of R is not observed. Then it is necessary to perform the experiments at a frequency such that wave length is equal to $\delta$ which is the condition expressed by the relation: $k\delta = 2\pi$.

From the general equation of attenuation:

$$\alpha = c\,\omega^{m} \quad ; \quad (\omega = 2\pi f) \tag{8}$$

it is a simple matter to show that:

$$\beta = \frac{d\alpha}{d\omega} = c\,m\,\omega^{m-1} = \frac{m\alpha}{\omega} = m\,\frac{\alpha}{2\pi f}$$

when the wave length is equal to $\delta$ :

$$\beta_{\delta} = \frac{1}{2\pi}\,\frac{m\cdot\alpha_{\delta}\cdot\delta}{v}$$

or:

$$\frac{v\cdot\beta_{\delta}}{m} = \frac{\alpha_{\delta}\cdot\delta}{2\pi}$$

which can be combined with the expression (6) to obtain:

$$\frac{2\pi}{\alpha_{\delta}}\cdot\frac{v\,\beta_{\delta}}{m} \simeq \frac{\sigma_{y}}{2\varepsilon}\left(\frac{K_{Ic}}{\sigma_{y}}\right)^{2} \tag{9}$$

an expression which suggests the possibility of determining $\frac{K_{Ic}}{\sigma_{y}}$ from attenuation measurements.

## 2.2.1 - Measurements of acoustic velocity

In a first stage a measuring system conceptually simi-
lar to that described in the reference will be used.

The equipment will also permit the digital reading of
the time interval in order to implement data acquisi-
tion by the computer. This technique gives a precision
which is considered sufficient for the characterization
of the elastic constants and of the fracture toughness.

At the time of writing this report we have not received
the Tektronix 7D15 unit, in which the measurements are
based, so that it is neither possible to include any
experimental results nor to evaluate possible errors.

Fig. 3 shows the block diagram of equipment we will
use in acoustic velocity measurements.
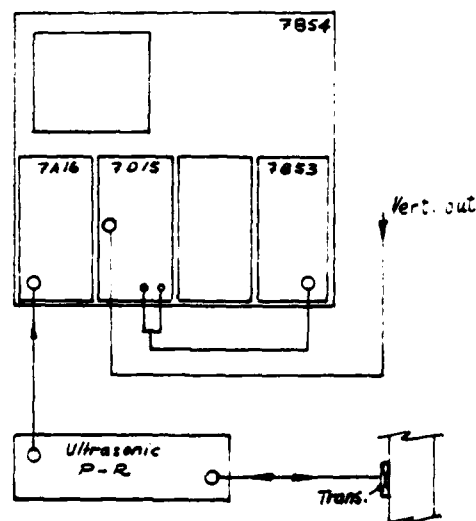


Fig. 3. Acoustic velocity measurements.

## 2.2.2 - Attenuation measurements

The technique proposed by E. Papadakis (7) using 5,10, 20 and 50 MHz commercial wideband transducers with water buffer for low and intermediate frequencies and quartz buffer for 50 MHz.

Echos of interest, usually first and second backwall echos, are FFT processed to calculate its power spectrum and a raw reflection coefficient is computed from handbook data for acoustic impedances. The amplitude relation curve is computed according the technique proposed by A. Vary (8) and given by the expression:

$$\alpha(f) = \frac{\ln(R/BB)}{2e} \qquad (10)$$

where:

R: reflection coefficient of the interface buffer-sample.

BB: amplitude relation at a given frequency for two echos.

e: sample thickness.

By an adequate regression technique it is possible to calculate the values of c and m in the equation:

$$\alpha = cf^m \qquad (11)$$

The diffraction correction is computed for low frequencies (usually below 15 MHz) and calculations for parameter $\beta$ to be used in equation (9) are performed.

## 3 - Equipment

The block diagram of the equipment to be used in our
experiments is shown in fig. 4. Some are experimental
units and others are in a workshop stage. Details are
given in the following paragraphs.
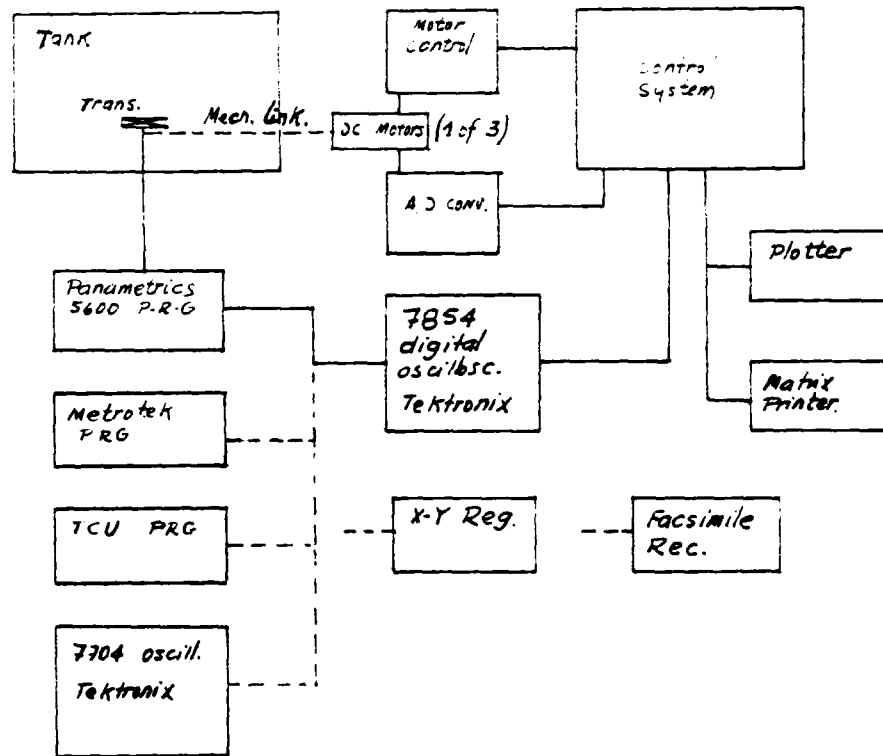


Fig. 4. Experimental equipment.

3.1 - <u>Automatically controlled ultrasonic inmersion test bed (SEICA).</u>

SEICA are the Spanish initials for the system which was defined at the starting of the program as a major goal between equipment objectives because it is fundamental for high precission and reproductibility tests to be performed.

Its fabrication has been subcontracted to SUZFECAR, S.L. and design will be done by INTA's and SUZPECAR's engineering personnel. Design and fabrication will be under control and supervision of Ultrasonic Laboratory's personnel. To this time minor details of mechanical and control design are being defined and, if everything goes well, the system will be ready for setting up tests by the end of the year.

A summary description of the main characteristics of the system is followed.

Inmersion tank is 1000 x 800 x 600 mm of useful dimensions. Mechanic searching system is formed by three orthogonal axes driven by dc motors with servocontrolled speed and digital position control by means of Hewlett Packard discs of 500 div/turn. All three linear movements are driven by high precision ball screws being longitudinal clearance consequently about zero in any of the three directions. Sliding of movable parts is always through ball bush in one of the supports and a free ball bearing in the other. This assembly was already experimented in a system built some years ago and has shown to be quite satisfactory because its nearly null clearance and very low friction.

Z axis has, additionally, the possibility to perform

a whole rotation around itself  not being this rotation motorized in a first stage.
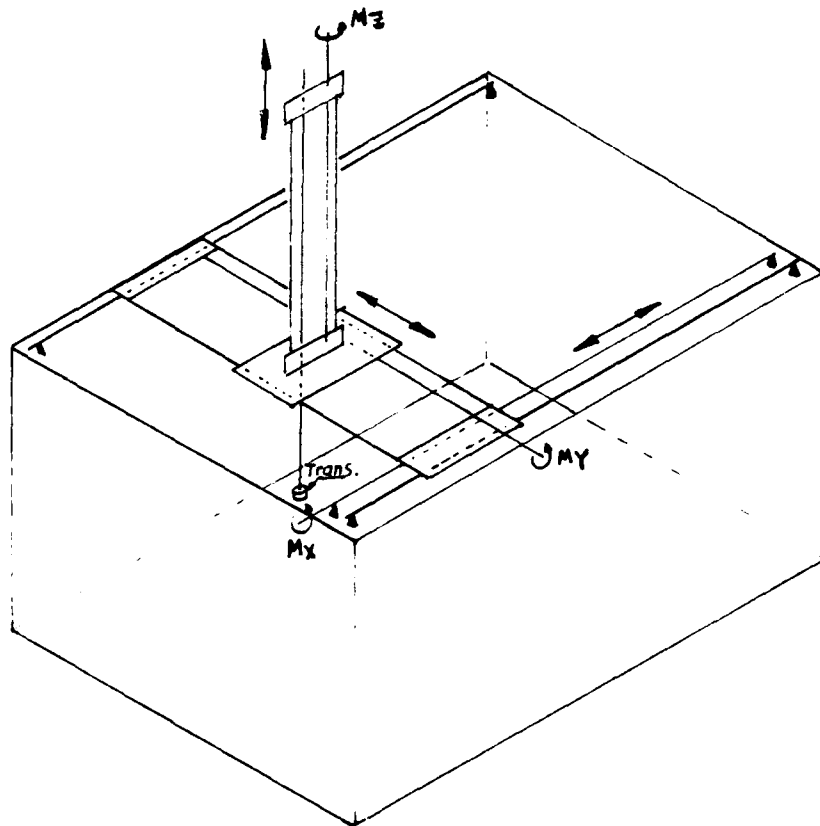
Fig. 5 shows a schematic draw of the mechanic parts.



Fig. 5. Schematic draw of inmersion tank.

Position is to be read within 0.01mm and repeatability will be better than 0.1mm at any point of the tank.

All the three movements are servocontrolled by an DRAC-1 micro processor, based on Rockwell AIM65. It has 22 K RAM memory. An alphanumeric screen 60 x 22 characters, a disk unit and a thermal printer act as peripherals.

The structure of the control system is shown in fig. 6.
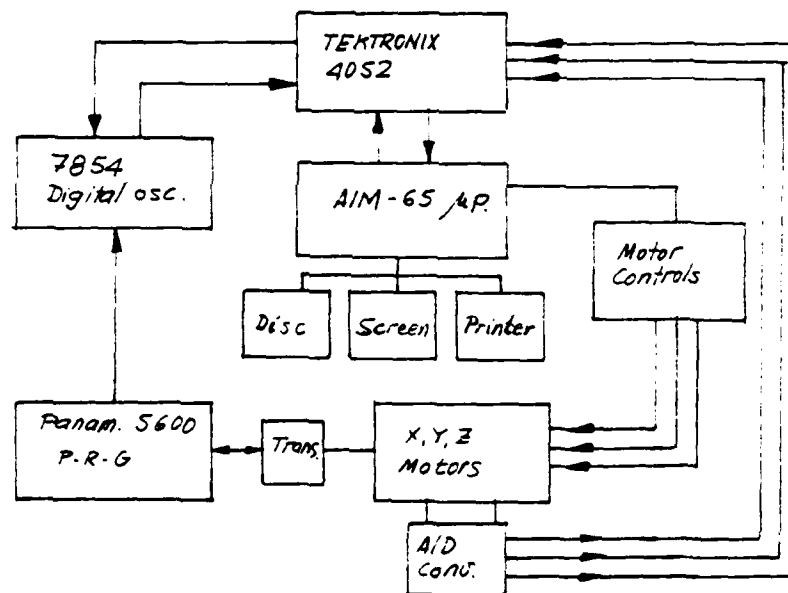


Fig. 6 Block diagram of control system.

The software for controlling the motors will be resident
in the EPROM memory of the microcomputer and will be
written in assembly language to make it as compact as
possible.

The master terminal is the 4052 computer and a multitas-
king program to control all the test bed operations will
be written (9).

The program will allow:

1 - Send commands to the microcomputer AIM65. Examples
of these commands would be request for current
coordinates of the transducer, halt or continue
commands.

2 - Allows the microcomputer AIM65 to send data to the
master terminal, to the disc memory or to the screen
(error messages, confirmation of data was received,
transducer coordinates).

3 - Store the control blocks for specific scan profiles.

4 - Allows to 4052 to send commands to the 7854 digital
oscilloscope to digitize the signal.

5 - Allows to the AIM-65 to accept digitized data and
to store this data into the disk memory or into
the tape memory.

6 - Stored data will be analyzed and if a threshold
value is exceeded, coordinates of such point will
be stored.

## 3.2 - Ultrasonic pulser-receiver

There are a Panametric 5600 pulser-receiver-gate,
(fig. 7a) up to 100 MHZ bandwith and a Metrotek system
(fig. 7b) including MP 215 Pulser, MR101 Receiver, MG701
stepless Gate and MP 702 Gated Peak Detector to be used
up to 20 MHz. There is also a 20 MHz pulser-receiver
and gate unit (fig.7c) built by J.P. Weight from the
Department of Physics of the City University, London.

## 3.3 - Signal acquisition and display

To digitize signals we will use a Tektronix 7854 digital
oscilloscope (fig. 7d) able to capture repetitive sig-
nals up to 400 MHz. The following plug-in units are
available in our Laboratory.

> 7A15A Linear Amplifier (80MHz bandwidth)
> 7A16A    "            "       (225MHz     "     )
> 7B53A Time base
> 7B50A    "       "
> 7L12  Analog spectrum analyzer (100 KHz to 1300 MHz)

In the next few weeks we hope to receive the digital
counter timer 7D15 to be used mainly in the velocity
measurement system.

For analog signals it is also available a Tektronix
7704 oscilloscope (fig. 7e).

There is a project to convert an analog X-Y recorder
into a facsimile recorder to be able to display C-scan
type signals. As shown in fig. 8, the output voltage
of a peak detector (VI) is feed into the ∓5 pin of
IC6 (L13914). The low level induced in some output is
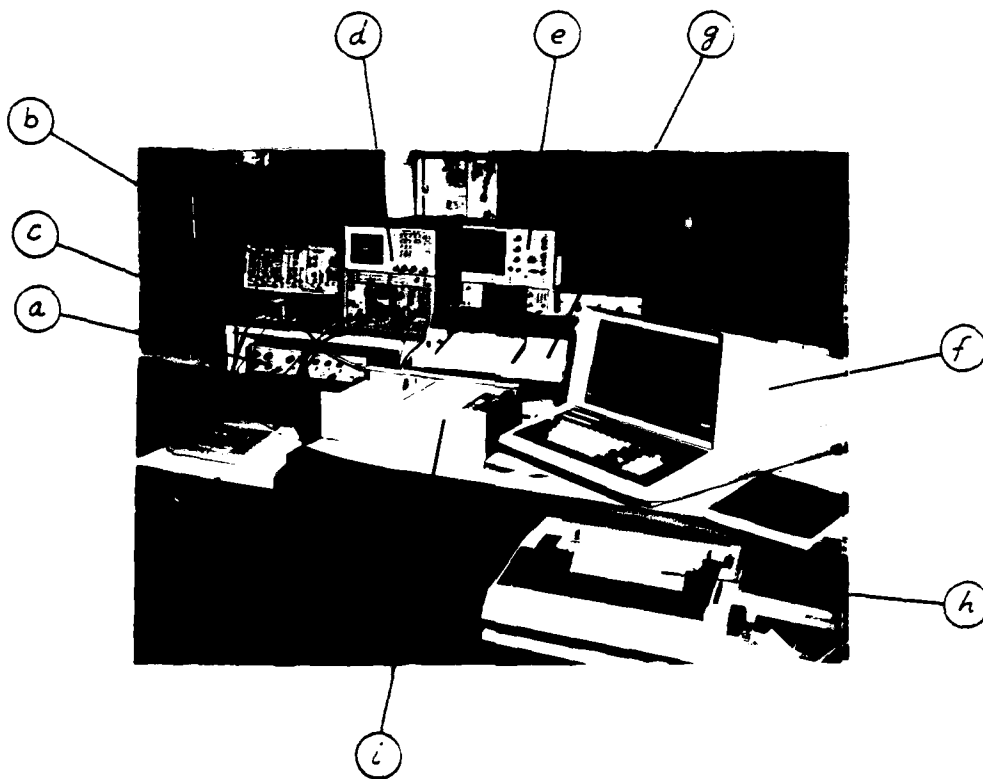inverted and used to saturate the transistor which gives

Fig. 7  Experimental equipment.

a fixed voltage (VB) at IC3. This voltage may be regulated with R1-R10 between 6 and 24 volts and is applied to the electrode placed instead of the pen of the analog X-Y register in which an electrosensitive paper sheet is used. Some LED's indicate the current output level and will be useful in calibrating stages.
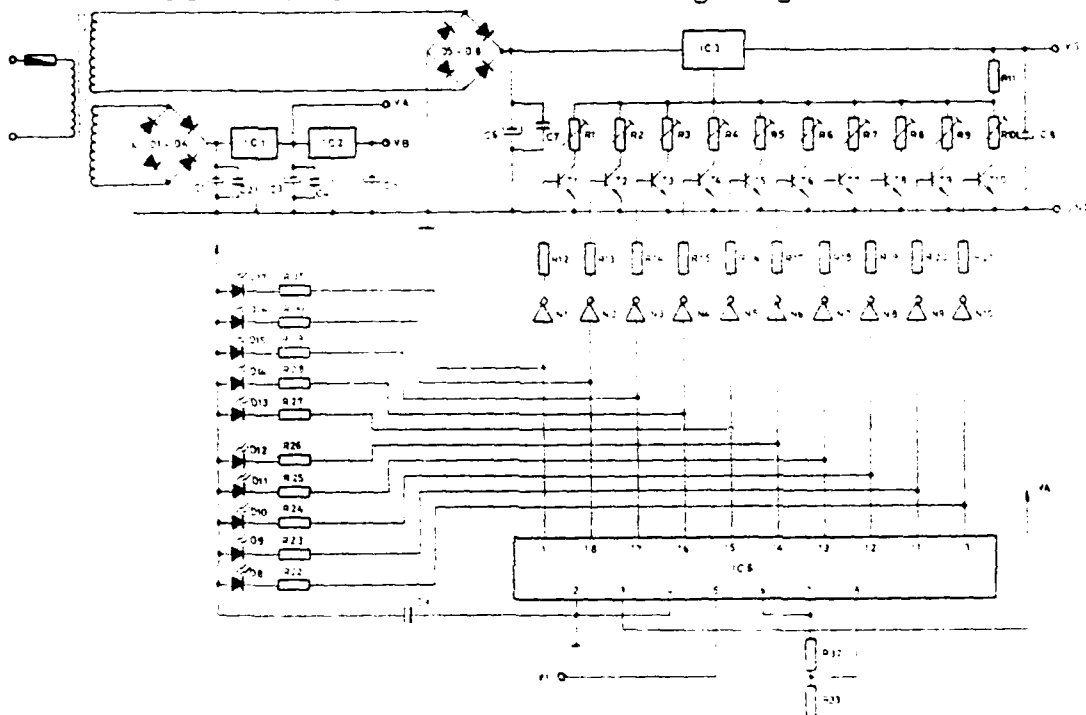


Fig. 8. Modification for X-Y register into a C-scan register.

3.4 - <u>System control and signal analysis</u>

It is based upon a Tektronix 4052 minicomputer (fig. 7f)
with 64K RAM memory and two ROM packs R07, R08 to be
used in signal analysis process.

As peripherals we have a digital plotter Hewlett-Packard
7470A (fig. 7g) and a matrix printer FACIT 4510 (fig.7h)

Major functions of control are given in paragraph 3.1.

4 - Software

In this first stage, software to acquire, analyze and display signals has been implemented in order to characterize materials.

Current program permits to perform any of the following operations:

- Select the number of points per waveform to be used in signal acquisition.

- Acquire signals.

- Store signals in tape file.

- Fourier transform to frequency domain. Amplitude and phase.

- Time and frequency domain signal conditioning.

- First and second derivatives to select frequency limits.

- Amplitude relation curve.

- Calculate the attenuation coefficient as a function of the frequency.

- Output to the plotter of any curve.

Two main difficulties have been found in making the software. One is related with the algorithm to perform FFT which, as is implemented in the ROM pack is quite useful for ultrasonic applications. That is because frequency window width is inverse to that of time window so that as greater the time definition of the signal, as lower is that of frequency. Three possible solutions are intended. First one is to utilize the oscilloscope to make a signal conditioning by means of the instruction HXPD (Horizontal expand) which, if a parameter less than one is used, a real compression is per-

formed keeping almost every accident of the wave. This
is useful for low and intermediate frequencies where
signals are not too short in time domain, so compression
is not too high. But this technique introduces heavy
uncertainities when frequencies are of the order of 20
MHz or above being then unuseful for materials charac-
terization.

Another possible way to solve this problem is to imple-
ment a routine for Discrete Fourier Transform which per-
mits to select starting and ending frequencies as well
as resolution results being fairly independent of the
time domain signal. In this way the spectra calculated
in the next paragraph have been made. The only diffi-
culty with this algorithm is that the time to perform
all the calculations is very long.

The third way is to implement a chirp Z-transform using
the FFT algorithm. This solution will probably offer
the best combination of resolution and time. We hope
to have this algorithm implemented in our program in
the next few weeks.

The other difficulty before mentioned is related with
the software to drive the digital plotter. Hewlett-
Packard 7470A is a very cheap instrument although its
quality/price ratio is very high and was selected because
of some budget limitations. Unfortunately, low cost
hardware often comes together with high cost (time)
software, and that is the major reason because complete
software package for materials characterization, and
even defect, has been impossible to be completed on
time.

## 5 - Experimental results

Experiments have been carried out on steel samples of chemical composition:

| C | Mn | Si | P | S |
|-------|-------|-------|-------|-------|
| 0.16% | 1.45% | 0.27% | 0.02% | 0.04% |

Two different heat treatments have been considered and their respective microstructures are shown in fig. 9.



a) as rolled                    b) quenched

Hardness: 28 HRC                Hardness: 46 HRC

Fig. 9. Microstructure of tested samples.

Samples of 30 x 50 x 5mm thick were machined and ground finished.

A Panametrics 50MHz central frequency transducer with fused quartz buffer rod was used and medium motor car oil (SAE 30) as a coupling medium. To ensure uniform contact pressure and reproductible coupling conditions a simple device was built (fig. 10).

Fig. 11 shows a typical oscillogramme observed with A-scan when a rolled sample is tested.

To acquire signals sweep of time base must be much faster in order to improve resolution. Fig. 12 is the echo B1 in fig. 11 but which 10 nsec/div instead of 1$\mu$s/div. This is a good image to be acquired but jitter is a little disturbing as shown oscillogramme in fig. 13, where three signals are averaged to improve sharpness of the digitized signal.

We have not still studied the influence of jitter on frequency spectrum but it seems not to be very strong as can be shown by comparing with spectrum such as that displayed in fig. 15a; fig. 15b is the calculated spectrum of the signal in fig. 13 and fig. 15c is the calculated spectrum for the smoothed signal of fig. 14.
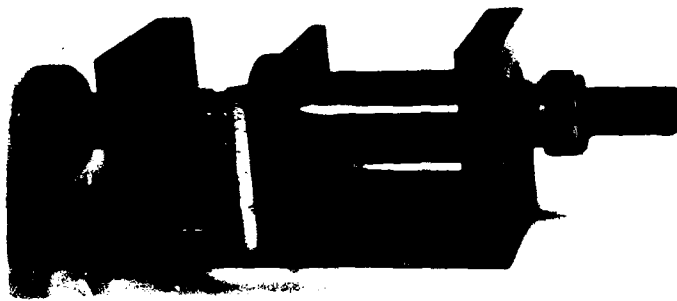
Fig. 10. Coupling transducer to sample device



A1: First interf. echo

B1: First backwall echo

B2: Second   "        "

B3: Third   "        "

A2: Second interf. echo

B21: First backwall echo
from the 2nd sequen
ce.
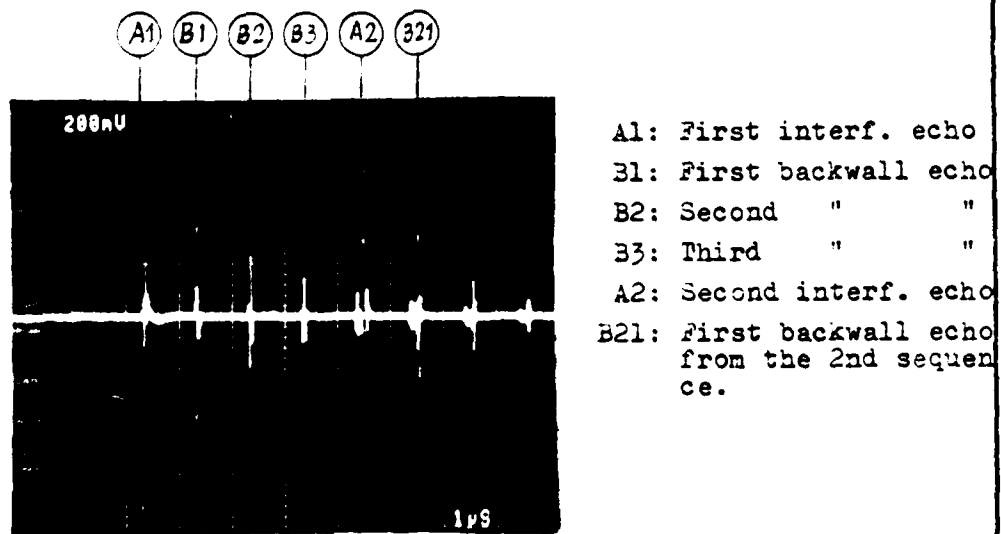
Fig. 11. Interface and backwall echos of as
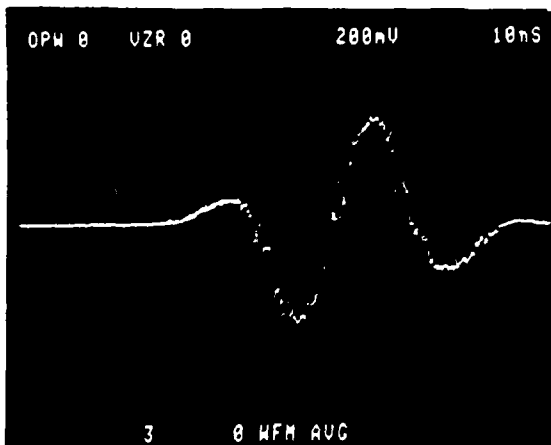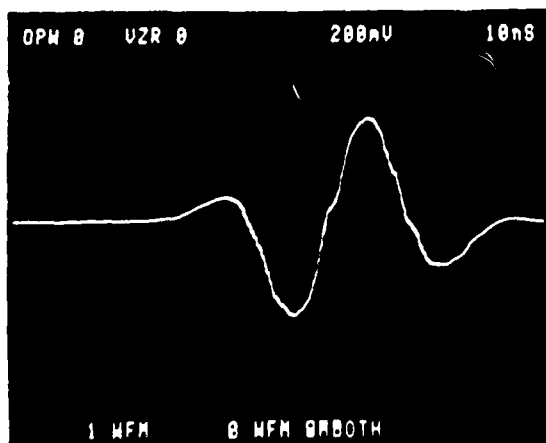rolled sample.
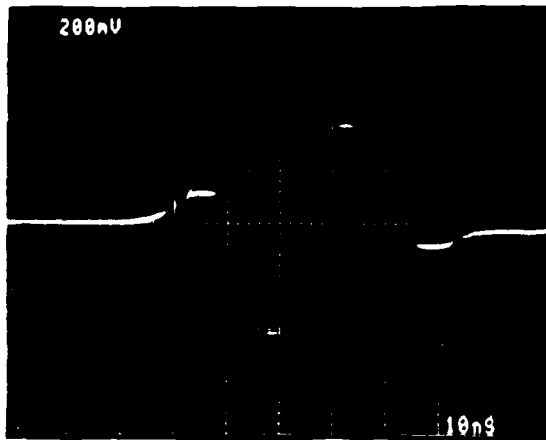
Fig. 12   Echo 31 in fig. 11.



Fig. 13   Echo 31 acquired.
Jitter of analog signal is
the cause of poor sharpness.
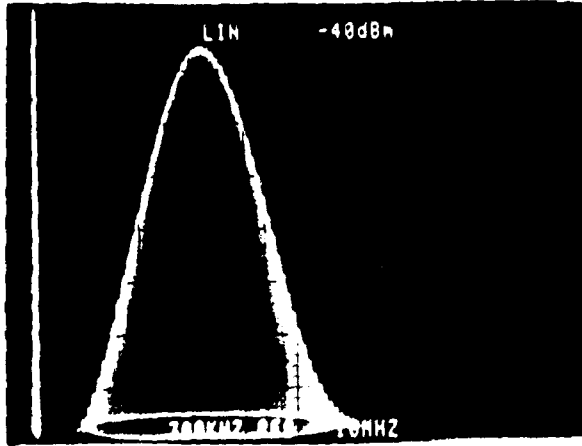


Fig. 14   Same as fig. 13 but
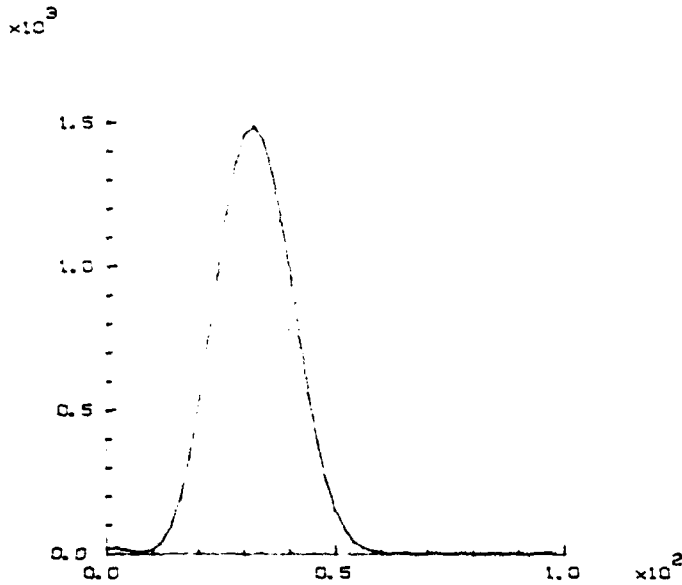.2 smoothed.

Fig. 15a Analog spectrum of signal in fig. 12.



Fig. 15b Calculated spectrum for the signal in fig. 13.
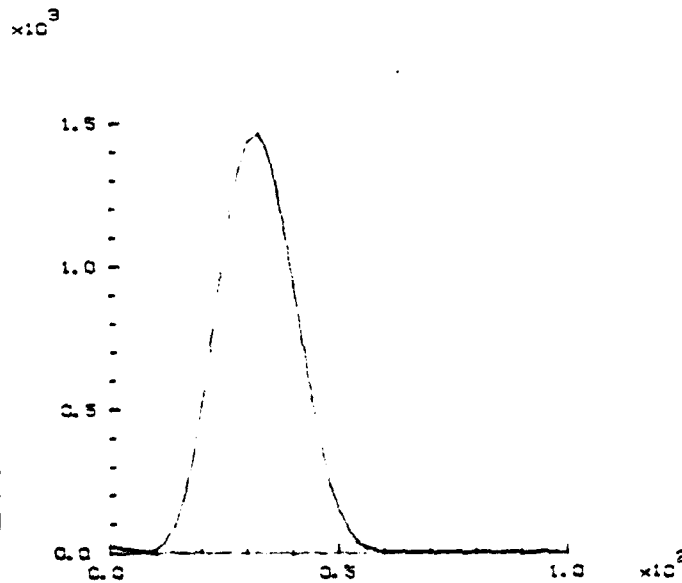


Fig. 15c Calculated spectrum for the signal in fig. 14.

The results described herein are derived from the analysis of echos B1 and B2 in both as rolled and quenched samples. Testing technique are intended to be similar to that of A. Vary in reference (8). The results are shown in fig. 16.

Time domain signals (fig. 16 a,d) are the result of averaging 10 waves samples in order to avoid jitter effects. B1 and B2 signals are overlaped only for easy to compare purposes.

Results of Discrete Fourier Transform (DFT) are shown in fig. 16 b,e). The difference between both samples is easy to see in a qualitative way by comparing the high frequency band of the spectra.

To make this difference quantitative first and second derivatives of the spectra are calculated and limits of validity are defined between the first maximum of first derivative and the second maximum of second derivative.

A new DFT is performed between the limits increasing the resolution relative to other spectra and the amplitude relation $(B_2/B_1)$ curve is computed. Now upper and lower bounds for reflection coefficient are defined using handbook data for acoustic impedances (10):

Sample .............. $45.10^6$ $Kg/m^2$.S
(steel)

Coupling agent ...... $1.5\ 10^6$ "
(motor oil)

Buffer .............. $14'5.10^6$ "
(fused silica)

Lower limit is R=0.51 and represents the pure buffer-sample interface. Upper limit is R=0.93 and comes from considering the pure oil-sample interface. The actual R coefficient must obviously be between these limits
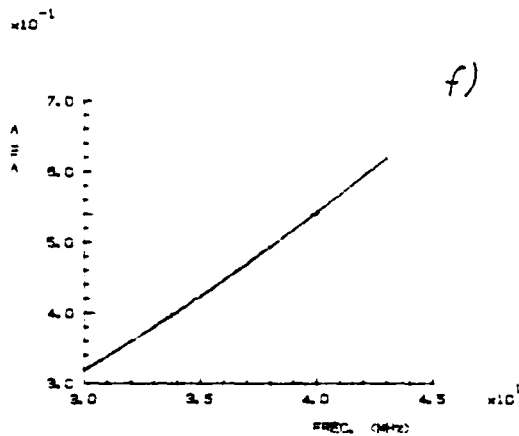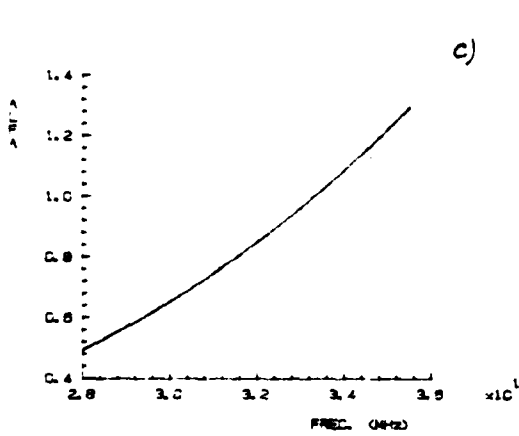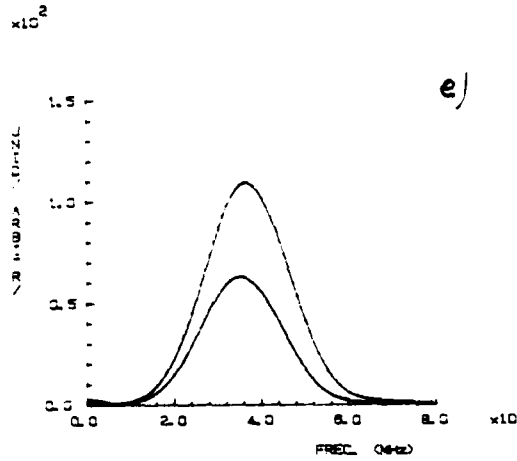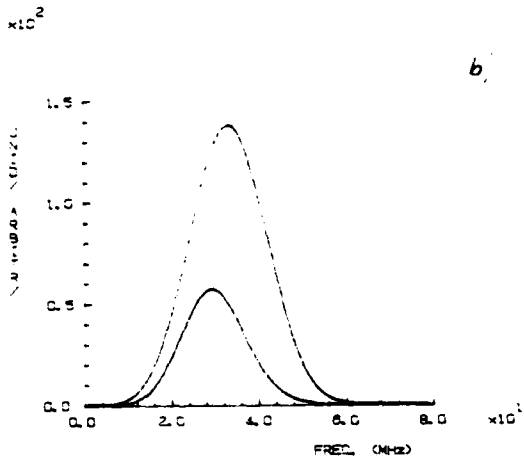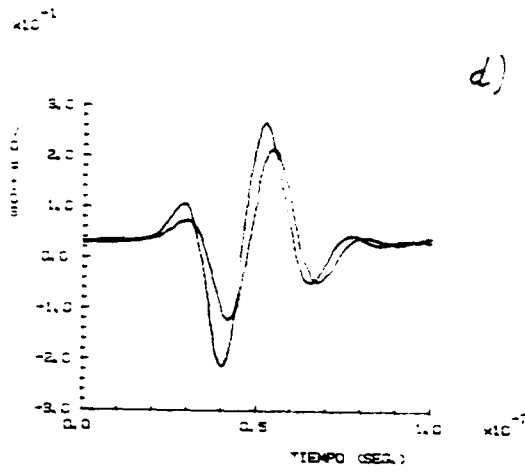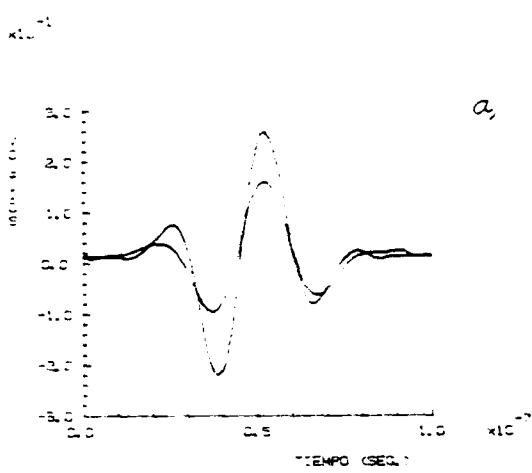
Fig. 1 Ultrasonic results for as rolled and quenched samples.

and there are some different ways to determine its value.
To do that we have chosen the technique described by Vary
which consist in select as actual value of R the one that
gives the best fitting between real and calculated atte-
nuation curve. Starting with R=0.9, the equation:

$$\alpha = \frac{\ln\left(\frac{A_1 \cdot B}{C}\right)}{2t} \tag{12}$$

is solved for alpha at each frequency and from the curve
obtained, values of c and m in the equation:

$$\alpha = c f^m \tag{13}$$

are derived by a simple regression technique. Then fit-
ting of curve from equation (13) with that of amplitude
relation is calculated. A new value of R is then inten-
ded (i.e. R = 0.8) and all the process is repeated until
a best value of fitting is obtained.

Results obtained by this technique are the following:

|  | As rolled |  | Quenched |
|---|---|---|---|
| R | 0,6515 | | 0,730 |
| C | $6,59.10^{-7}$ | | $2,78.10^{-4}$ |
| m | 4,061 | | 2,0529 |
| fitting | 0,99996 | | 0,99990 |

The values of c are in good agreement with that reported
in the literature (11), (12). Attenuation versus frequen-
cy curve is shown in fig. 16 c and f.

A different way to calculate the attenuation function
is to solve for R and alpha the pair of equations:

$$B_1 = A R^2 t\ e^{-2\alpha t}$$
$$B_2 = A R^2 t\ e^{-4\alpha t}$$

This technique is similar to that proposed by Papadakis
(7) and is also reported by N. Grayeli etal. (11) and
will be implemented in our computer in the next future
as a part of second year effort.

## Conclusions and recommendations

- Preliminary work to implement a computer based ultra-
  sonic characterization program has been carried out
  and results for the exponent of the frequency agrees
  well with that of other authors.

- Nevertheless a great deal of work must be developed
  in order to:

    - Study repeatability.
    - Study sources of error.
    - Complete software to make it as versatile as
      possible.
    - Collect experimental data from fracture toughness
      samples.

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